



The sPHENIX Forward Angle Spectrometer

Richard Seto for the PHENIX Collaboration

Department of Physics and Astronomy, University of California, Riverside 92521

Abstract

sPHENIX is a major upgrade proposed for the PHENIX detector. As part of this proposal, a forward spectrometer to cover the rapidity range $1 < \eta < 4$ is in a conceptual stage to complement the detectors in the central region. The forward rapidity region is important for the study of high density of gluons in a nucleus, as well as for the measurement of the spin structure of the nucleon. Some of the basic physics goals and a possible detector configuration are outlined.

Keywords: QCD, CGC, sQGP, RHIC, PHENIX

1. Introduction

The sPHENIX detector, proposed in [1] is the first stage of a major upgrade to the PHENIX detector, which replaces the present central magnet with a solenoid, thereby removing the large iron yoke at forward rapidity that acts as a hadron absorber for the current muon detectors. This will allow for the addition of a forward spectrometer, covering $1 < \eta < 4$, with the capability of measuring hadrons, electrons, photons and jets. One of the primary goals of the forward sPHENIX spectrometer (fsPHENIX) is the study of cold nuclear matter (CNM) in proton-nucleus collisions. Additional goals include the study of spin asymmetries in transversely polarized $p^\uparrow + p$ collisions as well as the possibility of making measurements in heavy ion collisions. The design is such that sPHENIX could naturally be evolved into a detector for the study of electron-proton and electron-nucleus collisions, with the advent of a future high intensity electron beam at RHIC.

2. Gluon Saturation and Cold Nuclear Matter

One of the main goals of the sPHENIX forward spectrometer is to understand the dynamics of partons, primarily gluons, at very small momentum fraction (x) and high density. The gluon distributions in a nucleon rapidly increase as one goes to low- x . Because of the uncertainty principle, however, they also increase in transverse size and begin to overlap and recombine, resulting in saturation. In the case of a nucleus, this effect is magnified by a factor $A^{1/3}$ reflecting the nuclear thickness. One of the most successful descriptions of this phenomenon is the Color-Glass Condensate (CGC) [2]. Two hints of this saturated state of gluons are the suppression of forward hadron production and the disappearance of the correlations of back-to-back hadrons in $p+A$ collisions. As in the case of many other phenomena related to QCD (e.g. jet triplicity as a signature of gluons and the correctness of QCD as a theory, or

Email address: richard.seto@ucr.edu (Richard Seto for the PHENIX Collaboration)

flow and suppression of high p_T hadrons as a signature of the sQGP), it appears as if there may be no incontrovertible signature of the CGC [3]. There are other seemingly competing descriptions, namely transverse momentum dependent (TMD) parton distribution functions (PDFs), and higher twist formulations [4] of shadowing. Recently, however, the CGC and the TMD approaches have been shown to be equivalent for certain kinematical ranges [5].

The goals of the forward sPHENIX program will be to measure the parameters relevant to the CGC, namely the saturation scale Q_{sat} , and the predicted gluon distributions which manifest themselves in distributions of hadrons, photons and jets. As with other advances made in QCD, a preponderance of measurements consistent with the theoretical expectations will serve to substantiate the basic ideas. There are two gluon distributions of importance, the Weizsäcker-Williams distribution, $G^{(1)}$, and the dipole distribution, $G^{(2)}$ [5]. Single particle observables can only give a limited amount of information. However, for direct photon(γ_{direct})+jet and dijet final states, one can calculate an effective parton momentum fraction x , given by the usual relationship between x and two measurable quantities, rapidity and p_T . The γ_{direct} +jet and dijet final states in p+A collisions have different sensitivities to the gluon distributions $G^{(1)}$ and $G^{(2)}$. The γ_{direct} +jet process depends only on $G^{(2)}$, while dijet processes are dependent on both $G^{(1)}$ and $G^{(2)}$. One can begin by making measurements of γ_{direct} +jet to determine $G^{(2)}$, then by making measurements of dijet events and knowing $G^{(2)}$, one can extract $G^{(1)}$. In addition, γ_{direct} +jet events can also be used to make a measurement of Q_{sat} . Recent work by Jalilian-Marian and Resaein [6] shows that the strength of the correlation between a direct photon and an opposing hadron is sensitive to the saturation scale. The correlation between virtual photons, as measured by Drell-Yan pairs, and hadrons has also been studied [7]. While the latter is a very difficult measurement because of the low cross section which would yield only several thousand pairs in a typical 20 week run of p+Au, we are exploring the possibility of colliding protons on lighter ions since increase in luminosity more than compensates for the fact that there will be fewer binary collisions, although the effects due to saturation may also be correspondingly smaller. All of these detailed measurements will take time and require a detector with good photon identification, reasonable jet resolution and good acceptance. Once the data is taken and analyzed, however, one can assemble the results into a complete picture, which should indicate whether the basic tenets of the CGC model or other models are correct.

An intriguing new signature utilizing polarized proton+nucleus (p^\uparrow +Au) collisions has been suggested [8]. The single transverse spin asymmetry A_N , is defined for a forward moving vertically polarized proton beam, which scatters with its products to the left of the beam, as

$$A_N \equiv \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow},$$

where the arrows indicate the direction of beam polarization. The authors indicate that the strength of A_N measured in p^\uparrow +Au collisions relative to transversely polarized p+p (p^\uparrow +p) collisions would be directly related to the saturation scale. The most straightforward reaction would have a charged or neutral pion in the final state, where the asymmetry is known to be large in p^\uparrow +p collisions at forward rapidity [9]. Such a measurement is unique to the RHIC complex, the only machine in the world which can deliver polarized proton+nucleus collisions. These measurements will, of course, be extended to other final state particles, e.g. γ_{direct} , jets, heavy quarks, and quarkonia.

3. Other Physics

The goals of the sPHENIX forward spectrometer, encompass more than the study of gluon saturation effects. These other goals have significant influence on the detector design. Additional studies in CNM will include studying (a) the mechanisms that cause transverse momentum broadening and energy loss of partons in CNM and (b) hadronization mechanisms and time scales and their modification in a nuclear environment. In addition to the study of nuclear matter, there will be a significant program to study the origin of nucleon spin. Two of the signatures of major importance are Drell-Yan pairs and jets. The high luminosity available for 500 GeV center of mass collisions, the large acceptance of the forward arms, and long running periods of 20 weeks, will yield enough DY pairs for a significant measurement. We are also exploring the role fsPHENIX could have in studying Au+Au collisions. One of the key questions that might be probed is the mechanism of equilibration and formation of the sQGP, since the forward arms together with the central barrel will have very large rapidity coverage for the study of long range correlations. fsPHENIX will also have the capability to study the sQGP under a variety of densities, since the rapidity plateau drops to about half of its maximum in the acceptance of the forward arms at RHIC energies.

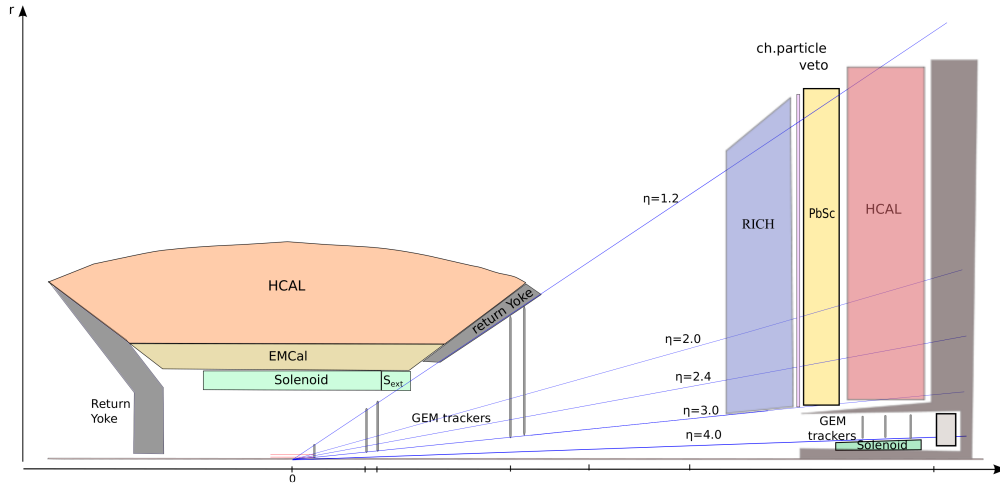


Figure 1: A straw man layout of a possible detector for a future forward upgrade to sPHENIX.

4. Detector Considerations

The broad range of physics topics to be explored by fsPHENIX, require a detector similar to the central barrel, capable of measuring photons and jets. In addition, Drell-Yan measurements for the spin program require excellent dilepton identification and the ability to reduce backgrounds from correlated charm and beauty decays. Both the CNM and spin programs require vertexing capability to identify heavy quarks. There are two significant differences between the requirements for the forward arms as compared to the central barrel. The first is that very forward rapidity measurements must be done at small angles to the beam, where the density of particles is high, and momenta are large. The second is the need for hadron particle identification, primarily for spin physics, to avoid cancellation of transverse spin effects in the fragmentation of different hadrons, since these effects are dependent on the flavors of the quarks involved in the process.

The forward sPHENIX study group has been investigating detector performance design requirements needed to meet the desired physics goals. The envisioned fsPHENIX forward spectrometer will have an acceptance from a pseudorapidity of 1.2 to 4. The acceptances of the mid-rapidity upgrade and the forward upgrade will be matched as closely as possible in order maintain a uniform acceptance for jet measurements. Currently, a “straw man” design (Fig. 1) is being used for the purpose of sensitivity studies. This design divides fsPHENIX into two sections.

The first section covers a region of η from 1.2 to 3.0. In this region, an extension or modification of the central solenoid provides a sufficiently strong magnetic field for good momentum resolution. Gas Electron Multiplier (GEM) detectors provide charged particle tracking. Silicon detectors are located near the collision point, to provide vertexing capability for heavy quarks. Particle identification is based on a Ring Imaging Cerenkov Detector, and will probably be usable only in the low multiplicity environment of $p^\uparrow + p$ collisions, though it may also be useful in $p + A$ collisions. The forward electromagnetic calorimeter consists of a reconfiguration of the current PHENIX electromagnetic calorimeters (EMCal) and would be followed by a hadronic calorimeter with modest energy resolution (HCAL). The front face of the EMCAL would be located between 3 and 5 meters from the interaction point. The HCAL together with the EMCAL provide sufficient jet resolution for use in $p^\uparrow + p$ and $p + A$ collisions. The capability of the spectrometer to measure jets in Au+Au collisions is under study, both in terms of physics reach and detector capability. A charged particle veto or pre-shower detector would be located in front of the EMCAL to aid in photon identification. Studies are underway to determine the feasibility of tracking muons with a muon identifier behind the HCAL, which would allow for di-lepton measurements to be made in both the electron and muon channels.

In the very forward section, from $\eta = 3$ to 4, an additional source of magnetic field would be needed to retain the momentum resolution. Currently, the design calls for a radial magnetic field with tracking provided by GEM detectors located in the magnet. A reconfiguration of the current lead tungstate Muon Piston Calorimeter, which provides the measurement of electromagnetic showers, is located behind the tracking detectors. The possibility of adding hadronic calorimetry in this region is currently being discussed. It must be emphasized that this design is

undergoing a process of significant evolution, but the present “straw man” design provides the basis of studies to better define and demonstrate the capability of the fsPHENIX detector to address the physics goals outlined.

5. Conclusion

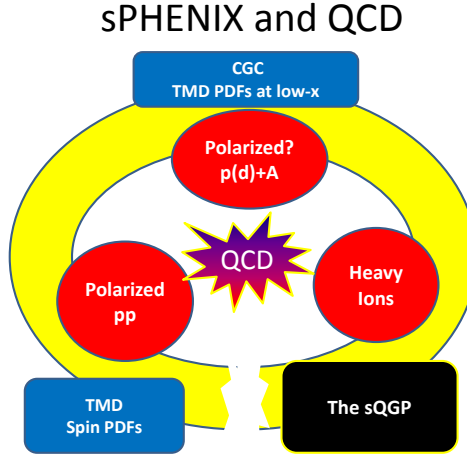


Figure 2: A schematic diagram to emphasize the fact that three areas of QCD study which have seemed disparate in the past, actually have a close relationship, both in the theoretical techniques used to understand them and in the interconnectedness of the phenomena exemplified by them.

While the precise physics signatures and detector design are still in a conceptual stage, the basic physics goals are clear. They are: (a) to elucidate the nature of gluons at small x in a nucleus, and to measure the relevant parameters and distributions such as Q_{sat} and the Weizsäcker-Williams and dipole gluon distributions, both for an intrinsic understanding of the saturation of gluon density, and as the initial state of the sQGP; (b) to understand the nature of nucleon transverse spin, and its connection to orbital angular momentum; (c) to understand the early stages of the formation of the sQGP. One of the highlights of recent developments in theory and experiment, is the extent to which the three areas of relativistic heavy ion collisions, the study $p+A$ collisions and Cold Nuclear Matter, and the spin physics of the nucleon, are interrelated (Fig. 2). Transverse momentum dependent methods first used in the study of nucleon spin have also given insight into the saturation of gluon density. In fact transversely polarized $p^\uparrow + Au$ collisions may be a means of measuring Q_{sat} . In turn, high density gluons as described by a Color Glass Condensate model are probably the best candidate as the initial state for the strongly interacting Quark Gluons Plasma. The understanding of the strong interaction is an exciting field, with phenomena as rich and varied as manifestations of the electromagnetic interaction as exemplified by the fields of atomic and condensed matter physics.

References

- [1] C. Aidala *et al.* [PHENIX Collaboration], “sPHENIX: An Upgrade Concept from the PHENIX Collaboration” arXiv:1207.6378 [nucl-ex].
- [2] F. Gelis, E. Iancu, J. Jalilian-Marian and R. Venugopalan, Ann. Rev. Nucl. Part. Sci. **60**, 463 (2010) [arXiv:1002.0333 [hep-ph]].
- [3] J. Albacete, “How can we prove/disprove the relevance of Color Glass Condensate/saturation physics at the LHC?,” HP2012. Contribution elsewhere in the volume and slides at <http://agenda.infn.it/getFile.py/access?contribId=164&sessionId=18&resId=0&materialId=slides&confId=4157>
- [4] J. -W. Qiu and I. Vitev, Phys. Rev. Lett. **93**, 262301 (2004) [hep-ph/0309094].
- [5] F. Dominguez, C. Marquet, B. -W. Xiao and F. Yuan, Phys. Rev. D **83**, 105005 (2011) [arXiv:1101.0715 [hep-ph]].
- [6] J. Jalilian-Marian and A. H. Rezaeian, arXiv:1204.1319 [hep-ph].
- [7] A. Stasto, B. -W. Xiao and D. Zaslavsky, Phys. Rev. D **86**, 014009 (2012) [arXiv:1204.4861 [hep-ph]].
- [8] Z. -B. Kang and F. Yuan, Phys. Rev. D **84**, 034019 (2011) [arXiv:1106.1375 [hep-ph]].
- [9] J. Adams *et al.* [STAR Collaboration], Phys. Rev. Lett. **92**, 171801 (2004) [hep-ex/0310058].